

X-ray observations of the ‘composite’ Seyfert/star-forming galaxy IRAS00317-2142

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ABSTRACT

I present *ASCA* observations of IRAS00317-2142, the most luminous ($L_x \sim 10^{43}$ erg s $^{-1}$ 0.1-2 keV) of the ‘composite’ class of galaxies. This enigmatic class of objects presents narrow-emission line optical spectra classifying these galaxies as star-forming on the basis of the diagnostic emission line ratios; yet, the presence of weak H_α broad wings also suggests the presence of a weak or obscured AGN. The *ASCA* spectrum can be represented with a power-law with a photon index of $\Gamma = 1.76 \pm 0.08$. Strong variability is detected (by about a factor of three) between the *ROSAT* and *ASCA* 1-2 keV flux. These characteristics clearly suggest an AGN origin for the X-ray emission. However, the precise nature of this AGN remains still uncertain. There is no evidence for a high absorbing column density above the Galactic. Moreover, there is no strong evidence for an Fe line at 6.4 keV, with the 90 per cent upper limit on the equivalent width being 0.9 keV. Thus the X-ray spectrum is consistent with an unobscured Seyfert-1 interpretation. This discrepancy with the optical spectrum, may be explained by either a strong star-forming component or a ‘dusty’ ionised absorber. Finally, the possibility that IRAS00317-2142 may harbour a heavily obscured AGN where the X-ray emission is mainly due to scattered light, appears less plausible due to the high value of the $f_x/f_{[\text{OIII}]}$ ratio which is more indicative of unobscured Seyfert-1 type AGN.

Key words: galaxies: starburst – galaxies: AGN - galaxies:individual: IRAS00317-2142 – X-rays: AGN

1 INTRODUCTION

The *ROSAT* All-Sky Survey, RASS, (Voges et al. 1996) provided a wealth of information on the X-ray properties of nearby AGN. The cross-correlation of the RASS with the IRAS Point Source Catalogue (Boller et al. 1995, 1998), revealed a new interesting class of objects, named ‘composites’ by Moran et al. (1996), with high luminosities $L_x \sim 10^{42-43}$ erg s $^{-1}$. Their main characteristic is that their [OIII] lines are broader than all other narrow lines, forbidden or permitted (Moran et al. 1996). The diagnostic emission line ratio diagrams (Veilleux & Osterbrock 1987) classify these objects as star-forming galaxies. Yet, some of the ‘composites’ present broad H_α wings suggesting the presence of a weak or obscured AGN. The origin of the powerful X-ray emission remains unknown in these objects. Interestingly, the ‘composites’ show very similar optical spectra with those of the narrow-line galaxies (NLXGs) detected in deep *ROSAT* surveys (eg Boyle et al. 1995). The NLXGs have narrow line optical spectra, some with weak broad wings. Yet, the pow-

erful X-ray emission $L_x \sim 10^{42-43}$ erg s $^{-1}$ strongly suggests the presence of a relatively weak or a heavily obscured AGN.

The most luminous object in the ‘composite’ sample, IRAS00317-2142 has a luminosity of $L_x \sim 10^{43}$ erg s $^{-1}$ (0.1-2 keV) at a redshift of $z=0.0268$ (Moran et al. 1996). This galaxy belongs to a small group of galaxies, Hickson 4 (Ebeling et al. 1994). Its optical spectrum has been discussed in detail by Coziol et al. (1993). The diagnostic emission line ratios (eg $H_\alpha/[NII]$ vs $H_\beta/[OIII]$) classify it as an HII galaxy. Nevertheless, its high X-ray luminosity as well as the presence of a faint H_α wind in its optical spectrum (Coziol et al. 1993) would clearly assign an AGN classification to this object. Here, I present an analysis of the X-ray properties of IRAS00317-2142 using data from both the *ASCA* and the *ROSAT* missions. The goals are to understand the origin of the X-ray emission in this enigmatic class of objects, its possible relation to the NLXGs present in the deep *ROSAT* surveys and finally to constrain the ‘composite’ galaxy contribution to the X-ray background.

2 OBSERVATIONS AND DATA REDUCTION

IRAS00317-2142 was observed with *ASCA* (Tanaka, Inoue & Holt 1994) between the 11 and 12th of December 1995. I have used the “Rev2” processed data from the HEASARC database at the Goddard Space Flight Center. For the selection criteria applied on Rev2 data, see the *ASCA* Data ABC guide (Yaqoob 1997). Data reduction was performed using FTOOLS v4.2. The net exposure time is about 40 ksec and 37 ksec for the GIS and the SIS detectors respectively. The two GIS and the two SIS detectors on-board *ASCA* have an energy range roughly between 0.8-10 keV and 0.5-10 keV respectively. The energy resolution of the SIS CCD detectors is 2 per cent at 6 keV while of the GIS detectors is 8 per cent at the same energy. For more details on the *ASCA* detectors see Tanaka et al. (1994). A circular extraction cell for the source of 2 arcminute radius has been used. Background counts were estimated from source-free regions on the same images. The observed flux in the 2-10keV band is $f_{2-10\text{keV}} \simeq 8 \times 10^{-13} \text{ erg s}^{-1} \text{ cm}^{-2}$ while the one in the 1-2 keV band is $f_{1-2\text{keV}} = 2.5 \times 10^{-13} \text{ erg s}^{-1} \text{ cm}^{-2}$; the fluxes are estimated using the best-fit power law model below ($\Gamma = 1.8$).

ROSAT observed IRAS00317-2142 on two occasions. It was first detected during the RASS (exposure time 340 s). Its RASS flux is $2.7 \pm 0.46 \times 10^{-12}$ (0.1-2 keV), (Moran et al. 1996). It was also observed by *ROSAT* PSPC as a target during a pointed observation between the 22 and 23rd of June 1992 (exposure time 9.3 ksec). The derived flux was $2.7 \pm 0.05 \times 10^{-12} \text{ erg s}^{-1} \text{ cm}^{-2}$ in the 0.1-2 band, in excellent agreement with the RASS flux. In the 1-2 keV band the flux is $7.3 \times 10^{-13} \text{ erg s}^{-1} \text{ cm}^{-2}$ a factor of three above that of *ASCA* in the same band. There is no evidence for extension in the pointed *ROSAT* PSPC image (eg Pildis, Bregman & Evrard 1995) suggesting that the bulk of the X-ray emission originates in IRAS00317-2142 rather than being diffuse emission from hot intergalactic gas in the galaxy group. Here, I re-analyse the *ROSAT* data in order to make comparisons with the *ASCA* spectral fits and to perform joint fits with the *ASCA* data.

Throughout this paper I adopt $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $q_0 = 0$. For the spectral fitting I use XSPEC v.10. I bin the data so that there are at least 20 counts per bin (source and background). Quoted errors to the best-fitting spectral parameters are 90 per cent confidence regions for one parameter of interest.

3 SPECTRAL ANALYSIS

3.1 The *ASCA* spectral fits

I first fit a single power-law to the *ASCA* data. These are consistent with a zero hydrogen column density, N_H . Hence, hereafter, I have fixed the column to the Galactic column density ($N_H \sim 1.5 \times 10^{20} \text{ cm}^{-2}$). The results of the *ASCA* spectral fits are given in Table 1. Entries with no associated error bars were fixed to this value during the fit. The power-law slope $\Gamma \approx 1.8$, is consistent with the canonical spectral index of AGN (eg Nandra & Pounds 1994). Although this simple model provides an acceptable fit, $\chi^2 = 118.2/114$ degrees of freedom (dof), I have also added a Gaussian line component to the fit (the energy and the line width fixed at

6.4 keV and 0.01 keV respectively) as this is a common feature in AGN spectra. The additional component marginally improves the fit ($\Delta\chi^2 = 2.4$ for one additional parameter); this is statistically significant at only the 90 per cent confidence level. The 90 per cent upper limit for the equivalent width is 0.9 keV. In Fig. 1 the *ASCA* spectrum together with the best fit power-law model are given; the data residuals from the model are also plotted. The data have been rebinned in the plot for clarity. A Raymond-Smith (RS) thermal model results in a worse fit ($\chi^2 = 128.0/113$). The temperature derived ($kT=5.8 \text{ keV}$) is reminiscent of nearby normal galaxies. Next, I fit an ionised warm absorber model (eg Brandt, Fabian & Pounds 1996) in addition to the Galactic column density. Indeed warm absorbers are detected in more than 50 per cent of Seyfert 1s (Brandt et al. 1999). The temperature of the absorber is fixed at $T = 10^5 \text{ K}$ (Brandt et al. 1999). The best fit ‘warm’ column density is $N_H \sim 10^{22} \text{ cm}^{-2}$ while the ionisation parameter is practically unconstrained. However, $\Delta\chi^2 \approx 2.4$ for two additional parameters and thus the warm absorber model does not represent a statistically significant improvement.

I also attempt to fit a more complicated model with both a power-law and a RS component. This is because the optical spectrum strongly suggests the presence of a strong star-forming component. The spectral fit above yields $\chi^2 = 115.3/112$; the inclusion of the additional RS component is not statistically significant ($< 1\sigma$). I derive a spectral index of $\Gamma = 1.7^{+0.10}_{-0.10}$. The RS component has a temperature of $kT \sim 0.2 \text{ keV}$ lower but consistent with those of the star-forming regions in nearby galaxies (eg Read & Ponman 1997). The abundance remains practically unconstrained and thus it was fixed to the solar value ($Z = 1$). The luminosity of the RS component is $\sim 5 \times 10^{41} \text{ erg s}^{-1}$ or about 25 per cent of the total luminosity in the 0.5-2 keV band. Finally, a power-law and RS model is fit where the obscuring column densities are different in the two components. For example in many Seyfert-2, the power-law component is heavily obscured while the star-forming component is outside the obscuring screen and is relatively unobscured. However, both best fit columns are close to the Galactic disfavours the above scenario.

3.2 *ASCA* and *ROSAT* fits

Due to the low energy coverage of the *ROSAT* PSPC (0.1-2 keV) and its high effective area, it is quite instructive to fit the *ROSAT* data as well. Nevertheless, the energy resolution of the *ROSAT* PSPC is very limited ($\Delta E/E \sim 50$ per cent) at 1 keV. RS spectra have been fit to the *ROSAT* data by Saracco & Ciliegi (1995) and Pildis et al. (1994). They derive a temperature of $kT \sim 1 \text{ keV}$. Instead, I fit a power-law spectrum which is the standard model for AGN spectra at least in the small *ROSAT* band. I obtain a spectral index of $\Gamma = 2.63^{+0.04}_{-0.16}$ much steeper than the *ASCA* fit. The column density is $N_H = 3.4^{+1.0}_{-0.4} \times 10^{20} \text{ cm}^{-2}$ higher than the Galactic column ($\chi^2 = 82.1/82 \text{ dof}$). Finally, for the sake of completeness, I perform joint fits to the *ASCA* and the *ROSAT* data. However, bear in mind that this joint analysis has to be viewed with great caution. Recently Iwasawa Nandra & Fabian (1999) made spectral fits on *simultaneous* *ASCA* and *ROSAT* data of NGC5548. They demonstrate that the power-law fits may differ as much as $\Delta\Gamma \approx 0.4$

even in the common *ROSAT* / *ASCA* 0.5-2 keV band. The reason for this large discrepancy may be related with uncertainties in the calibration of both the *ASCA* and *ROSAT* detectors. A single power-law fit to the combined *ASCA* and *ROSAT* data of IRAS00317-2142 yields $\Gamma = 2.00^{+0.07}_{-0.07}$, $N_H = 1.9 \pm 0.2 \times 10^{20} \text{ cm}^{-2}$ ($\chi^2 = 227.2/197$ dof). The power-law normalization is allowed to vary freely between the *ROSAT* and the *ASCA* observation epoch. Next, a RS component is added to the model. The temperature is constrained to have an upper limit of 1 keV, otherwise the resulting temperature becomes unrealistically high (~ 15 keV). The best fit temperature is $kT = 0.07^{+0.02}_{-0.01}$ keV while the power-law slope is $\Gamma = 1.9^{+0.12}_{-0.03}$. Despite the inclusion of the additional RS component the fit did not improve ($\chi^2 = 231.4/195$ dof).

4 DISCUSSION

The detection of variability between the *ASCA* and the *ROSAT* data clearly suggests an AGN origin for the X-ray emission. The *ASCA* data are well represented with a single power-law $\Gamma \sim 1.8$ with no absorption above the Galactic $N_H \sim 1.5 \times 10^{20} \text{ cm}^{-2}$. Hence, the X-ray spectrum alone suggests a Seyfert-1 type AGN. This is again compatible with the high X-ray luminosity of this object, $L_x \sim 10^{43} \text{ erg s}^{-1}$, during the *ROSAT* observation. However, this interpretation comes in stark contrast with the optical spectrum which is indicative of a low luminosity or obscured AGN.

Then a few possibilities arise for the nature of the AGN in IRAS00317-2142. We could view a Seyfert-1 nucleus overwhelmed in the optical by the emission of a powerful star-forming galaxy. In the X-ray band the emission from the Seyfert-1 nucleus should dominate over that arising from star-forming processes. Still, according to the *ASCA* spectral fits, the luminosity of the RS component alone is $5 \times 10^{41} \text{ erg s}^{-1}$; this classifies IRAS00317-2142 as one of the most powerful X-ray star-forming galaxies known with a luminosity more than an order of magnitude above that of M82 (Ptak et al. 1997). The above scenario for the composites, which was originally proposed by Moran et al. (1996) can be tested by comparing the level of the H_α in respect with the hard X-ray luminosity. Indeed, Ward et al. (1988) found a strong correlation between the two quantities in a sample of IRAS selected Seyfert-1 galaxies. Then according to the scenario above, the composites should follow the same relation between L_x and broad $L(H_\alpha)$. The luminosity of the broad H_α component in our object is about half of the total H_α luminosity (Moran et al. 1996). Then the observed broad H_α luminosity is $L(H_\alpha) \sim 2 \times 10^{41} \text{ erg s}^{-1}$ (Coziol et al. 1993). This roughly translates to an X-ray luminosity of $L_x \sim 4 \times 10^{42} \text{ erg s}^{-1}$ according to Ward et al. (1988) not far off the observed X-ray luminosity of $L_x \sim 2 \times 10^{42} \text{ erg s}^{-1}$. Of course the long term X-ray variability observed introduces some level of uncertainty in the above test. Note that Bassani et al. (1999) reported the detection of a few Seyfert galaxies which possibly have a weak or absent Broad Line Region. Our object could in principle belong to this category. However, the $L_x/L(H_\alpha)$ ratio rather argues against this hypothesis. Again the possibility that the X-ray emission remains relatively unabsorbed while the optical suffers from additional obscuration cannot be ruled out. The

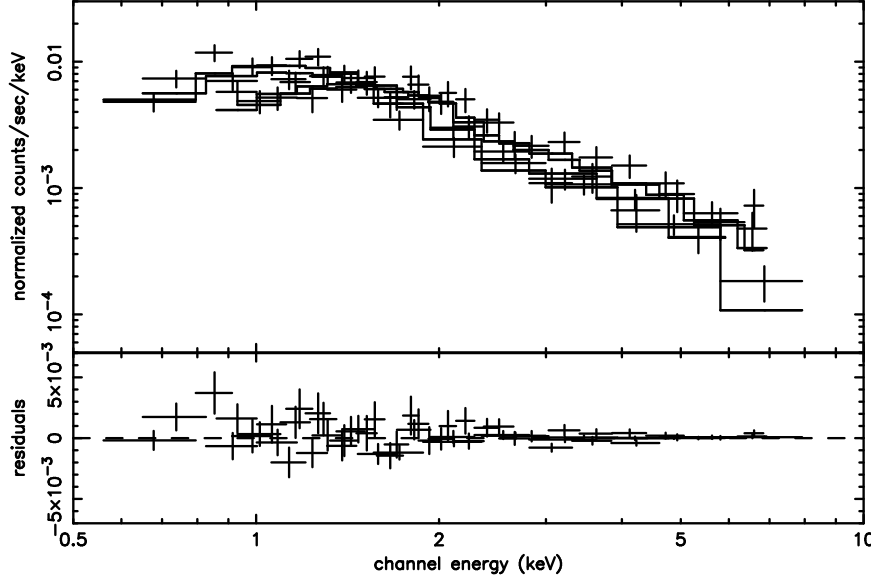
Balmer decrement in our object (using the flux of the narrow H_α and H_β from Moran et al. 1996) is about 5 corresponding to a column of $N_H \sim 10^{21} \text{ cm}^{-2}$ (Bohlin et al. 1978) is an order of magnitude higher than the column derived above in the case of cold absorption. The reason for this discrepancy is not obvious. One possibility is that the absorbing column is ionised: indeed in the case of a warm absorber the derived column is $N_H \sim 10^{22} \text{ cm}^{-2}$. Then some fraction of the 'warm' column should be located further away from the nucleus, where the narrow H_α and H_β lines originate.

Finally, IRAS00317-2142 could be a heavily obscured (Compton thick) AGN like eg NGC1068. Then a large fraction of the X-ray emission could be due to scattered X-rays, on a warm electron medium which should be situated well above the obscuring torus. The broad H_α wing observed could arise from scattered radiation. However, the narrow and broad H_α components have comparable fluxes (Moran et al. 1996) arguing against this interpretation. Note that, the peculiar combination of an un-absorbed X-ray spectrum with a narrow-line dominated, obscured optical spectrum was also encountered in NGC3147 (Ptak et al. 1996). This object has a type-2 type nucleus according to its optical spectrum which presents a relatively broad [NII] line (FWHM $\sim 400 \text{ km s}^{-1}$). The X-ray spectrum of NGC3147 is again very similar to our object as it shows no intrinsic absorption and a steep spectral index $\Gamma \approx 1.8$. Its observed X-ray luminosity is far below ($L_x \sim 10^{41} \text{ erg s}^{-1}$) that of our object; an Fe line at 6.4 keV (rest-frame) was clearly detected in NGC3147 (Ptak et al. 1996) with an equivalent width greater than 130 eV. Ptak et al. (1996) favoured a scenario where NGC3147 harbours an obscured AGN. If indeed IRAS00317-2142 is a heavily obscured AGN the intrinsic unabsorbed luminosity of this object should exceed $10^{45} \text{ erg s}^{-1}$ (assuming that we observe only a few percent of scattered light alone our line of sight). The column density should be above $N_H > 10^{24} \text{ cm}^{-2}$ in order to absorb all transmitted photons with energy up to 7 keV. Such a large column should produce a high equivalent width Fe line as the cold obscuring material is photoionised by the incident hard X-ray photons. For an obscuring column of 10^{24} cm^{-2} we expect an equivalent width Fe line of $\sim 1 \text{ keV}$ (see Fig. 3 of Ptak et al. 1996). This value is consistent with our 90 per cent upper limit for the Fe line equivalent width (0.9 keV). Probably the most stringent constraints on the AGN nature come from the X-ray to optical emission line ratios. Maiolino et al. (1998) argue that as the [OIII] emission comes from scales much larger than the obscuring torus, the $f_x/f_{[\text{OIII}]}$ ratio provides a powerful diagnostic of the nuclear activity. Hence, an obscured AGN should have very low $f_x/f_{[\text{OIII}]}$ ratio as the nuclear X-ray luminosity is obscured while the [OIII] is not. The ratio of the X-ray (2-10 keV) to the [OIII] flux (corrected for absorption using the formula of Bassani et al. 1999) is about 2.5 for our object. This is more typical of unobscured AGN (Maiolino et al. 1998) arguing against the obscured AGN scenario.

Additional constraints on the nature of the AGN could in principle, be provided by the observed variability. The Seyfert-1 objects should present rapid variability with the amplitude increasing as we go to lower luminosities (eg Nandra et al. 1997, Ptak et al. 1998). In contrast, the obscured AGN show little or no variability as a large fraction of the X-ray emission comes from re-processed radiation far away

Table 1. The spectral fits results on the *ASCA* data

Model	$N_H(10^{20}\text{cm}^{-2})$	$N_H^{warm}(10^{20}\text{cm}^{-2})$	Γ	Z	kT (keV)	ξ	χ^2/dof
power-law	1.5	-	$1.76^{+0.08}_{-0.08}$	-	-	-	118.2/114
warm-absorber	1.5	180^{+450}_{-170}	$1.82^{+0.10}_{-0.10}$	1	-	$358^{+\infty}_{-330}$	115.8/112
Raymond-Smith (RS)	1.5	-	-	$0.56^{+0.48}_{-0.39}$	$5.8^{+1.5}_{-1.3}$	-	128.0/113
power-law + RS	1.5	-	$1.71^{+0.10}_{-0.10}$	1	$0.18^{+0.47}_{-0.08}$	-	115.3/112

**Figure 1.** The best fit power-law fit to the *ASCA* spectrum of IRAS00317-2142 together with the corresponding residuals.

from the nucleus. However, in our case the *ASCA* light curves have poor photon statistics. Both the GIS and the SIS data (4 ksec bins) cannot rule out a constant count rate even at the 68 per cent confidence level. Therefore it is difficult to differentiate, on the basis of variability alone, between a Seyfert-1 and an obscured AGN scenario.

Regardless of the X-ray emission origin, the enigmatic composite objects present many similarities with the NLXGs detected in abundance in deep *ROSAT* surveys (eg Boyle et al. 1995). Many of these present clear-cut star-forming galaxy spectra. However, their high X-ray luminosities immediately rule out a star-forming galaxy origin for the X-ray emission. Only *ROSAT* data exist for these faint objects and therefore their X-ray spectra remain yet largely unconstrained (eg Almaini et al. 1996). Thus it is difficult to compare the X-ray properties of NLXGs with those of the 'composites'. However, it is interesting to note that if the *ROSAT* NLXGs have X-ray spectra similar to IRAS00317-2142, then they would make a small contribution to the X-ray background. Indeed, the X-ray spectrum of IRAS00317-2142 in the 2-10 keV band is much steeper than that of the X-ray background in the same band (Gendreau et al. 1995).

5 CONCLUSIONS

The X-ray observations shed more light on the nature of the composite objects. The detection of strong variability (a factor of three) between the *ASCA* and the *ROSAT* obser-

vations clearly suggests an AGN origin for most of the X-ray emission. Some fraction of the soft 0.1-2 keV X-ray emission can still be attributed to a strong star-forming component ($L_x \sim 10^{41-42} \text{ erg s}^{-1}$). Nevertheless, the exact AGN classification remains uncertain. The X-ray spectrum has a steep power-law slope ($\Gamma = 1.8$) and presents no absorption above the Galactic. Hence the X-ray spectrum is clearly suggestive of a Seyfert-1 interpretation. However, the optical spectrum shows only a weak H_α component and is therefore more reminiscent of an obscured Seyfert galaxy. The discrepancy between the optical and the X-ray spectrum can be alleviated if we assume that while the optical spectrum is influenced by the strong star-forming component, the AGN component is producing most of the X-ray emission; alternatively, it is possible that our object has a dusty ionised absorber which selectively obscures the optical emission. Finally, the possibility that our object is Compton thick (possibly like eg NGC3147) is disfavoured by the large value of the $f_x/f_{[OIII]}$ ratio which is more typical of unobscured AGN.

Future imaging observations with *Chandra* and high throughput spectroscopic observations with the *XMM* mission will provide the conclusive test on the above hypothesis.

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